Extending the Energy Box to Isolated Energy Systems

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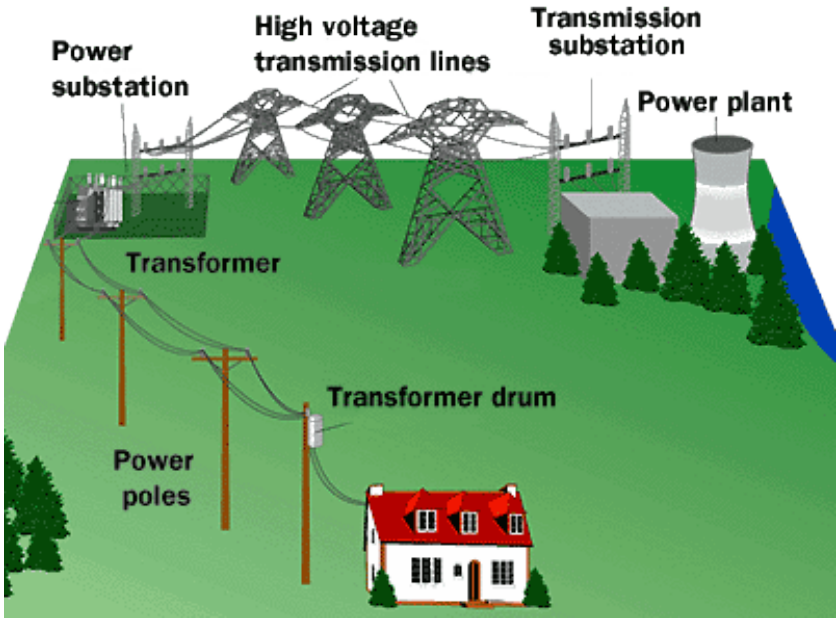
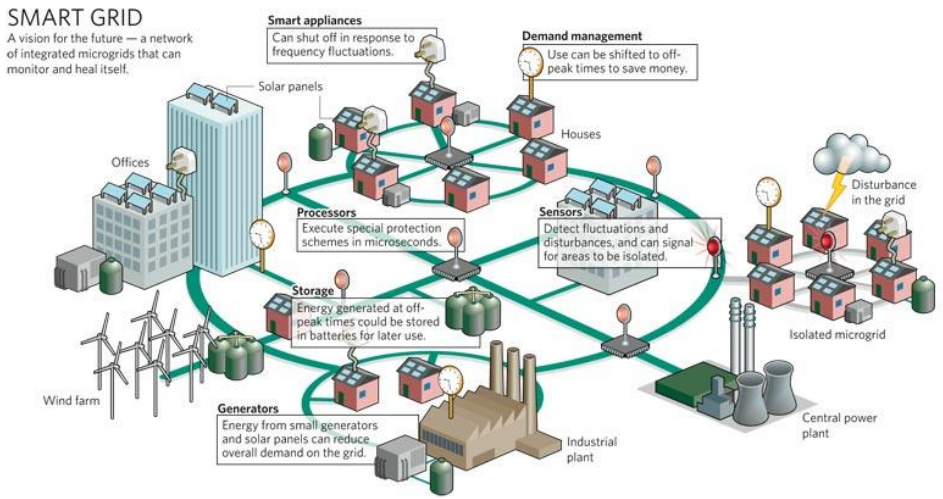
Presentation Outline

- Energy Box Research Framing
- Coordination **Within** a home
- Coordination **Across** homes (e.g. extending the Energy Box to Islands)

20th Century Electric Grid

21st Century Smart Grid





- Unidirectional flow of electricity
- Monthly metering and billing

- Bidirectional flow of electricity
- 'Smart' metering enables 'real-time' billing (e.g. hourly)

http://static.howstuffworks.com/
http://visual.merriam-webster.com/

http://www.consumerenergyreport.com/
http://www.pge.com/

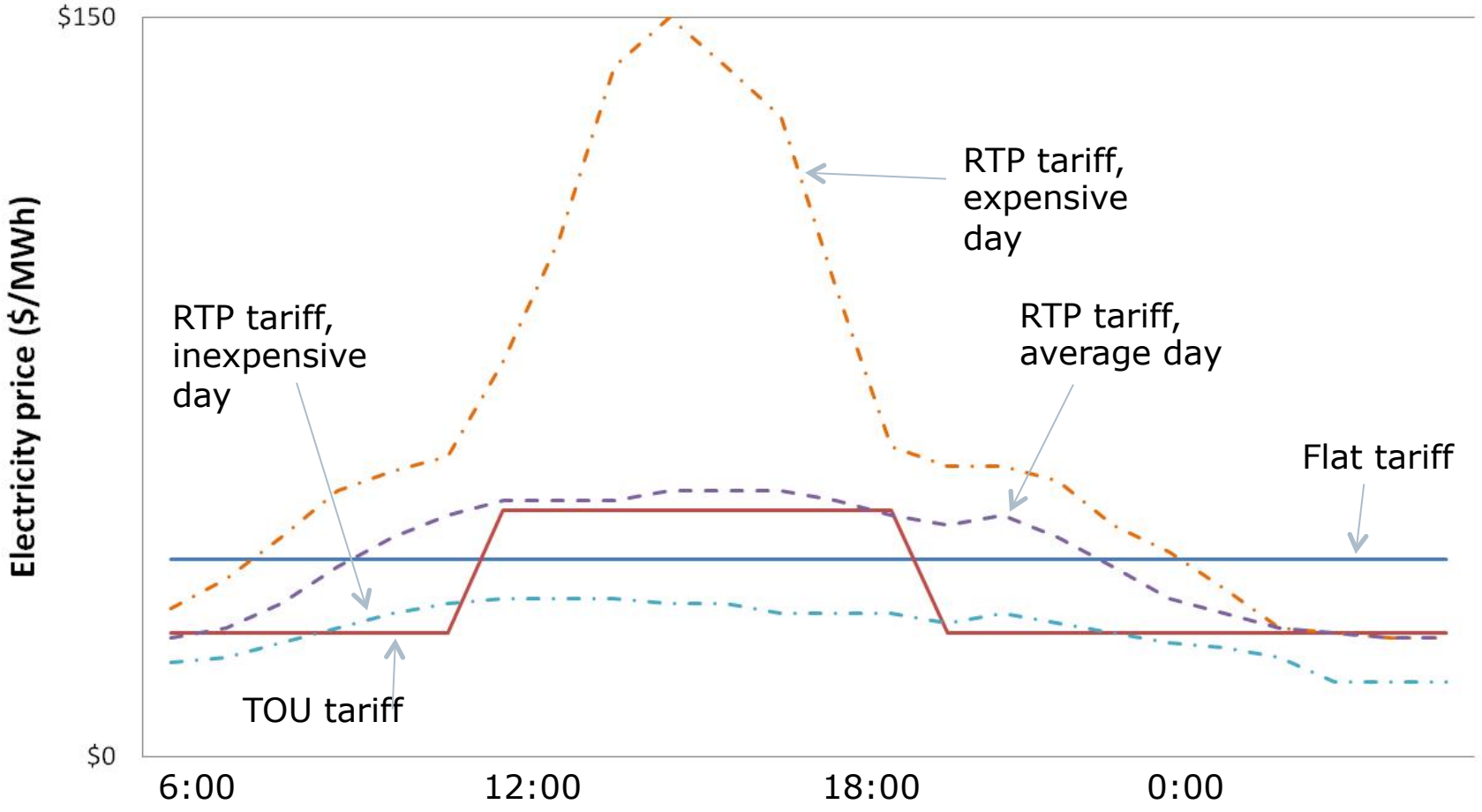
Balancing Electricity Supply and Demand

Strategies for Balancing Electricity Supply and Demand

	Peak Management	Days, Hours and Minutes	Seconds
Demand ⇩ Supply	▪ Direct load control [Le et. al. 1983] ▪ Energy efficiency programs ▪ Demand response (e.g. EnerNOC)	▪ Time-varying, demand-sensitive pricing [Schweppe et. al. 1980, Constantopoulos et. al. 1991, and many others]	▪ FAPERs [Schweppe et. al. 1980, Black and Ilic 2005, Brokish 2009] ▪ Grid-friendly Appliances™ [Hammerstrom et. al. 2007]
Supply ⇩ Demand	▪ Build new power plants	▪ Schedule power plant operations	▪ Automatic generation control (AGC)

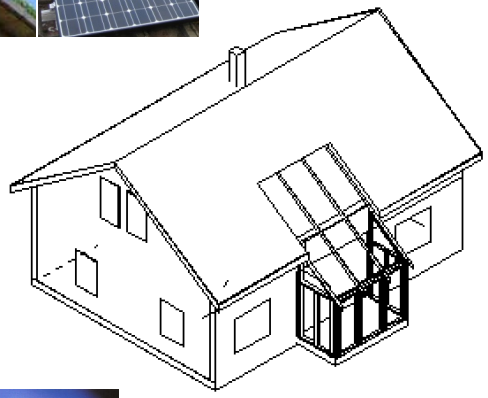
Time-varying Pricing Tariffs for Electric Energy ($/kWh)

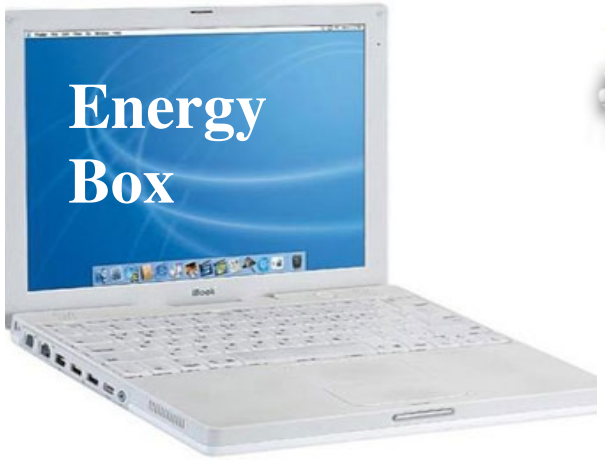
- Smart meters enable time-varying pricing



* Pricing data generated by the Energy Box simulation

Energy Box Illustration





The Energy Box:
A Home Energy Management System

Research Question: Coordination **within** a home

Assuming **time-varying pricing of electricity**, under what conditions is **coordinated control** of appliances and storage devices beneficial?

Benefits of Coordination in the Literature

Related cases in the literature when coordinated decision making outperforms independent decision making.	**Reference**
Any customer paying demand charges ($/kW)	Flohr [2010]
Any customer facing a power limit (maximum kW)	Morganti et. al. [2009a,b]
Any customer paying inclining block rates	Mohsenian-Rad and Leon-Garcia [2010]

Consumer

A/C

Prosumer = Producer + Consumer

A/C

Results Summary for Coordination **within** a home

Scenario Description	What matters?	In this scenario, could Coordinated decision making outperform Independent decision making?	
	$$$   &  forecast	N/A	
 	$$$   &  forecast	**No**: Chapter 4 of Livengood [2011] includes a mathematical proof	
 	$$$   &   forecasts	**Yes**: sell ≠ buy **No** : sell = buy	Chapter 5 of Livengood [2011]
  	$$$   ,   forecasts and the decision making process	**Yes**: sell ≠ buy **No** : sell = buy	Chapter 5 of Livengood [2011]

Expanding coordination **within** a home and scaling up to coordination **across** homes

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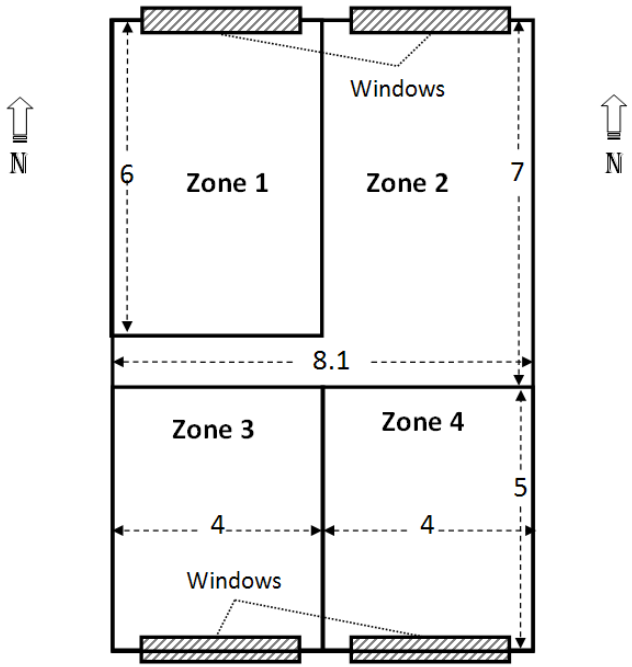
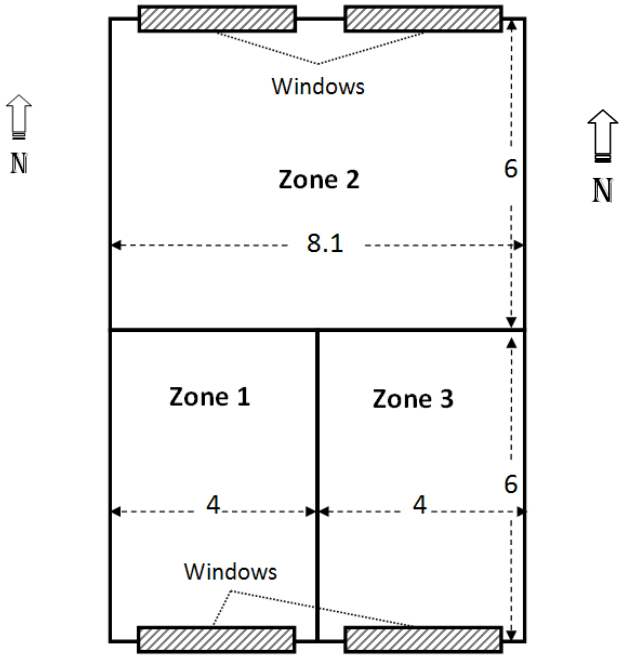
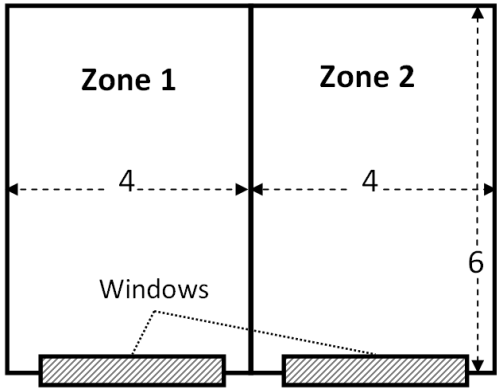
Zones for thermal differentiation

Additional savings may arise by dividing the home into zones and controlling thermal comfort in each zone based on occupancy patterns



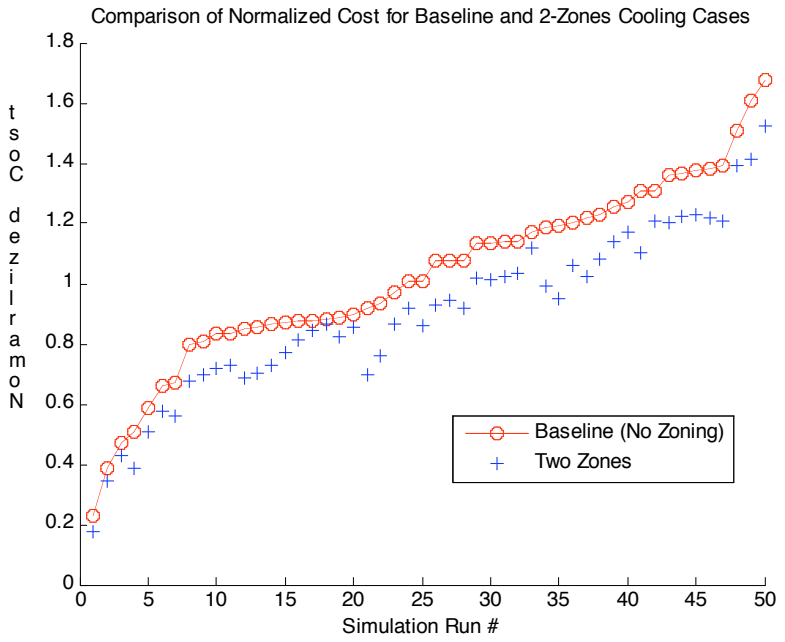


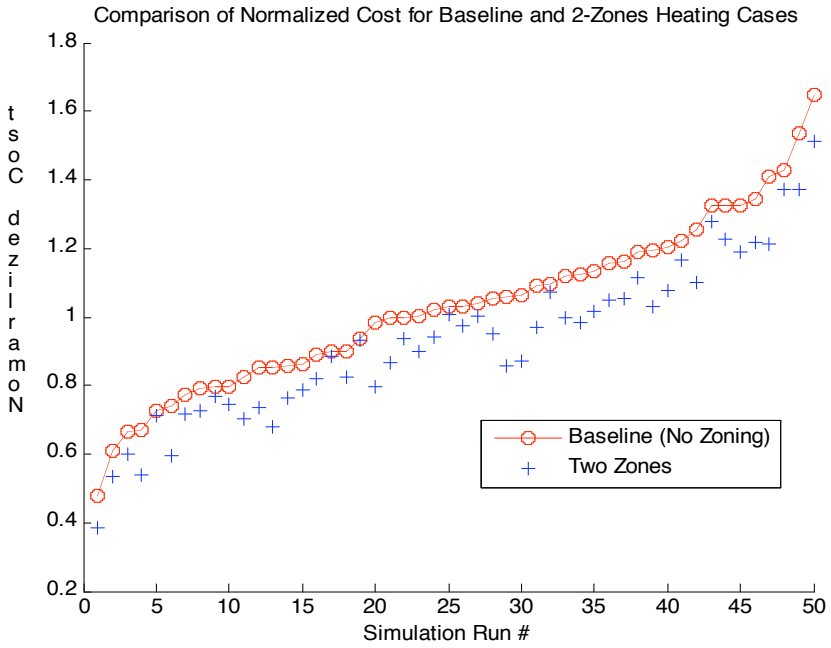


Preliminary Results: Additional Cost Savings from Zoning

Cooling
12.7%

Heating
10.0%

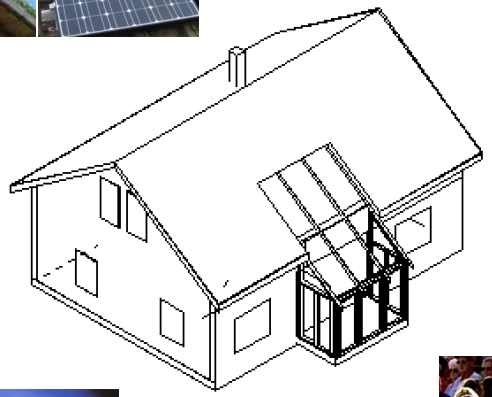




Other Energy Box Extensions

- Integrate all appliances, storage devices and distributed generation into the Energy Box model
- Build an Energy Box prototype that communicates with sensors and appliances in the home
- Install a prototype Energy Box in volunteers' homes to determine whether automation meets residents' expectations

Energy Box Illustration – coordination **across** homes



Coordination **across** homes

What are the 'best' strategies for coordination **across** homes? Open research question:

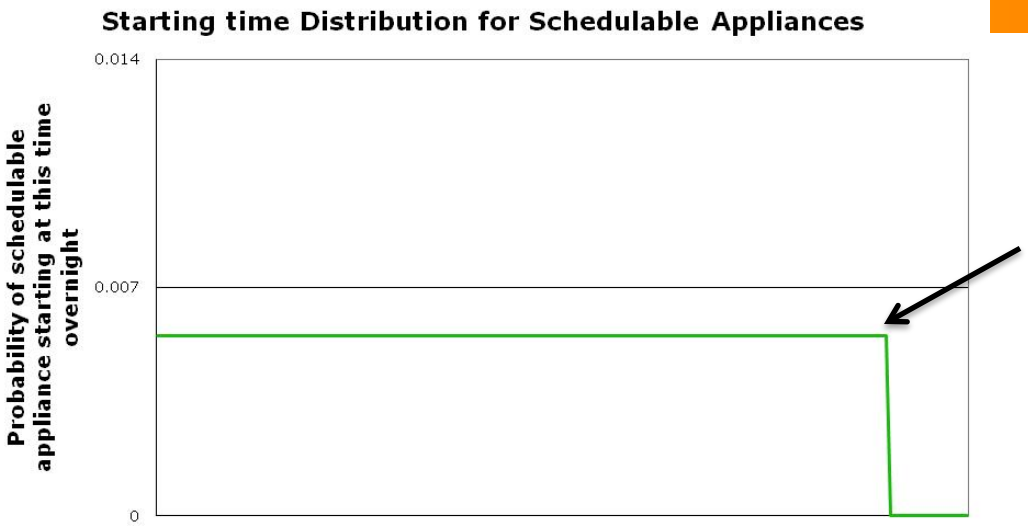
- Time-varying pricing? (consumer controls appliances)
- Direct load control? (utility controls appliances … ideally within consumer constraints)
- Aggregators?
- Centrally coordinated local control? (e.g. consumer controlled by selecting a random starting time from a utility-determined distribution)

Example of Centrally Coordinated Local Control

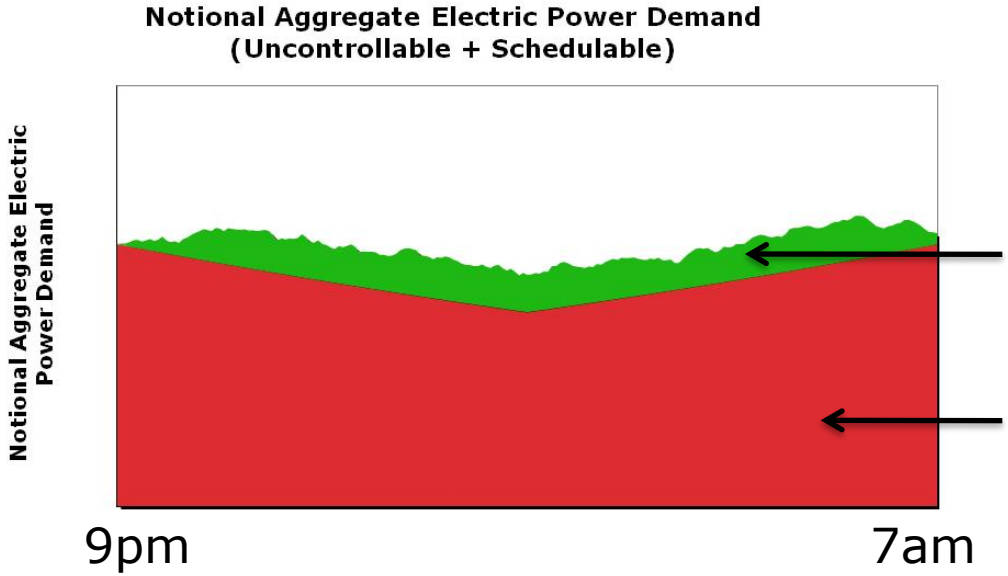
Assume that some residents have agreed to schedule appliances like dishwashers to run overnight.

The utility could broadcast a distribution of starting times to all participating appliances, and the appliance could then randomly choose when it will begin its load based on the distribution.

Example of Centrally Coordinated Local Control



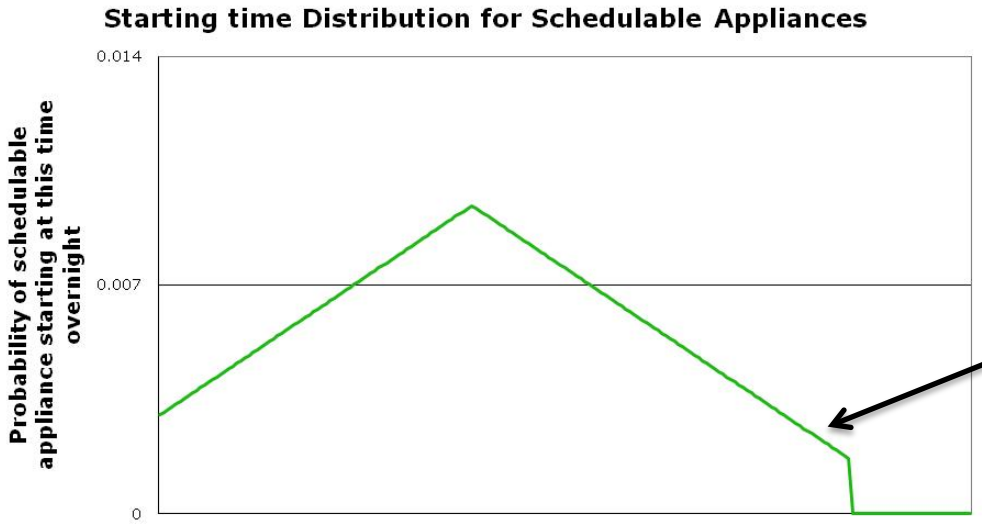
Uniform distribution of starting times, ensuring that the appliance completes its cycle by 7am



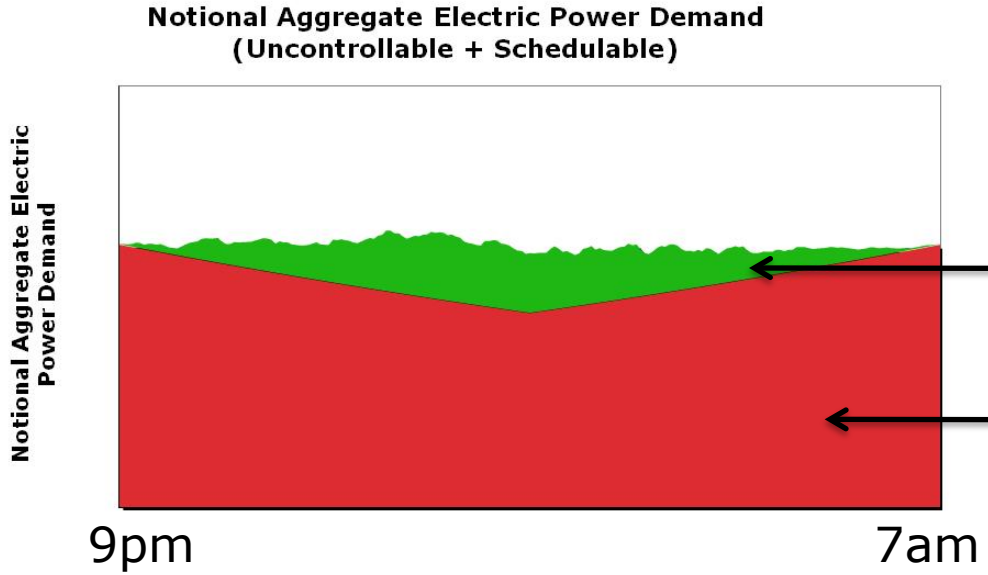
Schedulable electricity demand

Uncontrollable electricity demand

Example of Centrally Coordinated Local Control



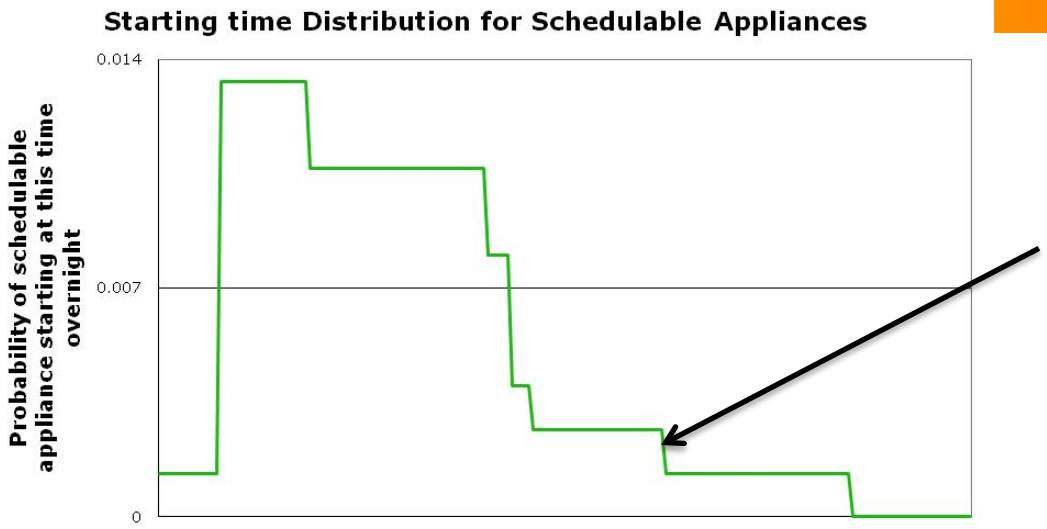
Triangular distribution of starting times still ensures that the appliance completes its cycle by 7am but also flattens the overnight aggregate electricity demand better than the uniform distribution



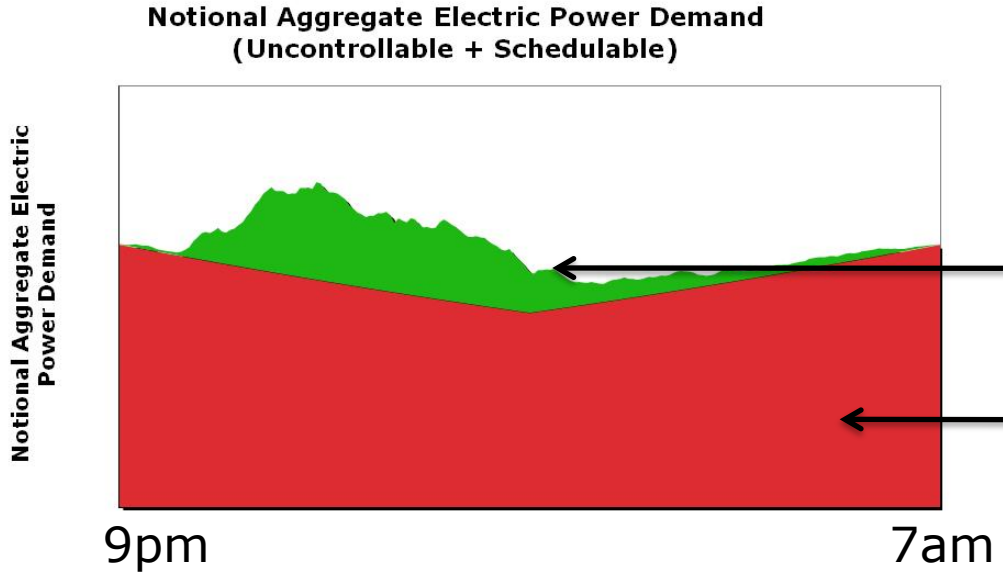
Schedulable electricity demand

Uncontrollable electricity demand

Example of Centrally Coordinated Local Control



The distribution of starting times could take on any shape to match the expected overnight supply of electricity from wind turbines, for instance



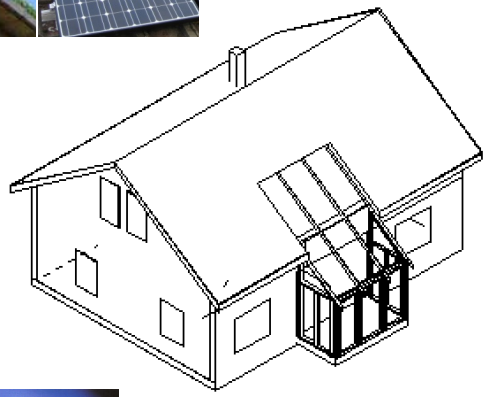
Schedulable electricity demand

Uncontrollable electricity demand

Potential research questions for Centrally Coordinated Local Control

- What is the desired aggregate demand curve?
- Given the desired aggregate demand curve, what is the best way to calculate the distribution of starting times that the utility should send out to participants in such a program?
- Will the desired aggregate demand curve be achieved consistently?
- How might this program expand or interact with similar programs for other end-uses?

Thank You!



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